EVALUATION OF WELD CHARACTERISTICS OF DISSIMILAR ALUMINUM ALLOYS USING FRICTION STIR WELDING WITH DIFFERENT TOOL PIN PROFILES

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***Abstract*—Friction Stir Welding (FSW) is a new joining process that has many advantages over other welding processes, including greatly reducing distortion and eliminating solidification. The present work aims to determine the feasibility to weld two pieces of aluminum pipe by friction stir welding process and study the effect on the mechanical properties of welding joints. In this research project two different types of tool pin profiles are used to join the dissimilar aluminum alloy sheets. The tool pin profiles are straight cylindrical and tapered cylindrical. In this project, study the influence of various tool pin profiles on the quality of the welding using three rotational speeds (rpm) at constant traverse speed (mm/min). This project covers the detailed study of friction stir welding of AA6061-AA6082 weld characteristics i.e., tensile properties like ultimate tensile strength, yield strength and %elongation. It also covers the metallographic properties of the weldments like microstructure and micro hardness at various zones**

***IndexTerms*— AA6061, AA6082, Ultimate Tensile Strength, Tool pin profiles, microstructure, micro hardness**

I. INTRODUCTION

Nowadays, researchers have been focusing on developing fast and eco-friendly processes in manufacturing and this include Friction Stir Welding (FSW) and Processing (FSP). Friction Stir Welding (FSW) is a solid–state joining technique invented and patented by The Welding Institute (TWI) in 1991 for butt and lap welding of ferrous and non–ferrous metals and plastics. FSW is a continuous process that involves plunging a portion of a specially shaped rotating tool between the butting faces of the joint. The relative motion between the tool and the substrate generates frictional heat that creates a plasticized region around the immersed portion of the tool [1] .

A rotating tool is pressed against the surface of two abutting or overlapping plates. The side of the weld for which the rotating tool moves in the same direction as the traversing direction, is commonly known as the 'advancing side'; the other side, where tool rotation opposes the traversing direction, is known as the 'retreating side'[2].Friction stir welding process uses a non-consumable rotating tool consisting of a pin extending below a shoulder that is forced into the adjacent mating edges of the work pieces as illustrated in Fig. 1. The heat input, the forging action and the stirring action of the tool induces a plastic flow in the material, forming a solid state weld [1].

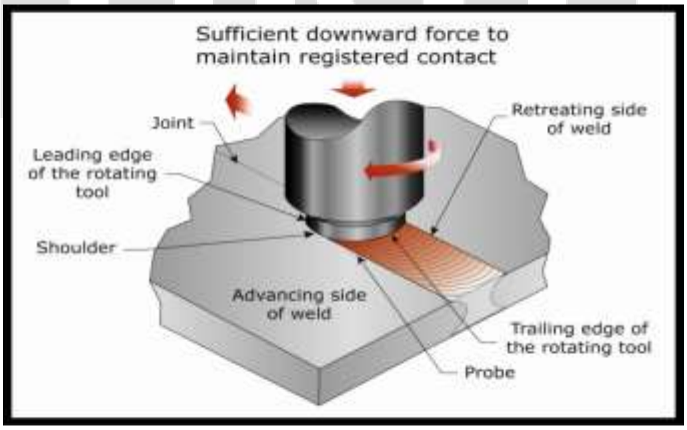


Fig.1. Schematic diagram of the Friction Stir Welding process

II. LITERATURE SURVEY

Beytullah Gungor *et al* [3] welded the similar and dissimilar of AA 5083-H111 and AA 6082-T651 using friction stir welding with the parameters of 1250 rpm of tool rotation, 64 mm/min welding speed and 2^0 tool tilt angle with the tool pin profile conically threaded. In this study, measured the tensile tests and bending tests. The results shows that tensile tests showed sufficient joint efficiencies and surprisingly high yield stress values (i.e.,193 N/mm^2). Bending fatigue test results of all joint types showed fatigue strength close to each other. The joint efficiency of AA5083 and AA6082 is 65%. Low speed friction stir welding of both similar and dissimilar alloy joints of 5083-H111 and 6082-T651 aluminum alloys revealed joints with high fatigue limits and satisfactory tensile strengths.

G. Gopala Krishna *et al* [4] joined the aluminum alloy 6351 with AA6351 and AA 5083 using the parameters of rotational speeds from 1000 rpm to 1500 rpm with constant travel speed and conical shaped probe tool pin profile through FSW. In this measured the tensile properties the results indicated strong relation between the rotational speed of tool and tensile properties of the welded joint. Yield strength, tensile strength and percentage of elongation of the joint decrease with the increase in speed of the tool and after reaching optimum values at 1300 rpm speed the values decreases with increase in speed of the tool.

Amandeep Singh *et al* [5] welded the dissimilar AA 6082 and AA5083 through friction stir welding using the parameters of rotational speeds 800,1100,1400,1700 rpm and tool feed 25,50,75,100 mm/min. in this study, observed the tensile properties the results show that the yield strength and UTS was increased with traverse speed up to 50 mm/min but decreased after that. The yield strength and UTS decreased with increase in tool rotational speed.

G. Venkat Ramana *et al* [6] joined the aluminum alloy 5083-HE15 with the aluminum alloys 6061-HE20 through friction stir welding using the parameters of rotational speed 1600 rpm and 2600 rpm , welding speeds of 15 and 20 mm/min using taper tool. In this study, measured the tensile properties and observed that at 1600 rpm and 20 mm/min shows higher UTS (157.331 MPa) and yield stress (123.368 MPa)values .

M. Bharathi *et al* [7] welded the aluminum alloys 5083 and 6082 through friction stir welding with multi pass that is one pass, two pass and three pass using the parameters of rotational speed 550 rpm and travel speed 17.4 mm/min for all joints using the threaded tool pin profile. From this it is observed that as the hardness value is almost 80% of the base material. From the results the optimal parameters for defect free welding is to be suggested.

III. MATERIALS AND METHODS

The material used for this investigation are aluminum alloys AA6061 and AA6082 of size (100X90X6) mm. The base material used for this experiment chemical composition is listed in Table I. A conventional milling machine is converted into friction stir welding machine for welding process. Mechanical properties of aluminum alloy AA6061 and AA6082 are represented in Table II.

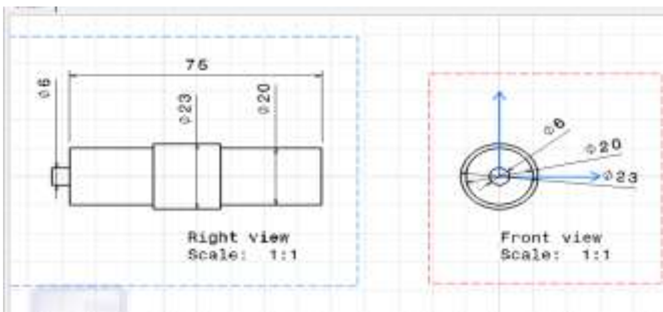
Table. I Chemical Compositions of AA6061 and AA6082

%Wt	**6061**	**6082**
Silicon(Si)	0.4 – 0.8	0.7-1.3
Iron(Fe)	0.7	0.5
Manganese(Mn)	0.13	0.4-1.0
Magnesium(Mg)	0.8-1.2	0.6-1.2
Zinc(Zn)	0.22	0.2
Titanium(Ti)	0.14	0.1
Chromium(Cr)	0.04-0.35	0.25
Copper(Cu)	0.2	0.1
Aluminum (Al)	balance	balance

Table.II Mechanical Properties of AA6061 and AA6082

Material	6061	6082
UTS(MPa)	310	360
0.2% Y.S(MPa)	270	322
Elongation (%)	13	16

Aluminum alloys of AA6061 and AA6082 were chosen for this experiment work. Dissimilar combinations of AA6061 with AA6082 friction stir welded in this experiment. Specially designed tools were used in this friction stir welding process. The tool material used in this work was high speed steel (HSS) with different tool pin profiles like straight cylindrical and cylindrical with tapered. The FSW tool was subjected to hest treatment process to improve hardness, the hardness of tool after heat treatment process is 50-55 HRC.



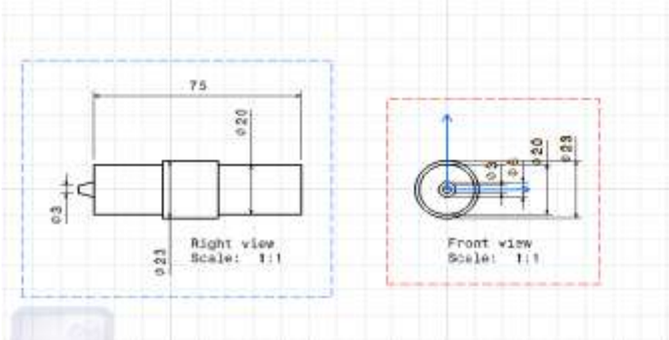


Fig 2 Schematic Representation of Line Diagrams of FSW Tools

A conventional milling machine is converted in to friction stir welding machine to carry out welding process. The two plates are partitioned in the fixture which is prepared for fabricating FSW joint by using mechanical clamps so that the plates will not separate during welding process. Two aluminum alloy plates of size (100X90X6) mm were perfectly clamped in milling machine bed on a back up plate. The FSW tool is inserted into the tool holder. Tool is plunged into the joint in the downward direction with the rotational speeds of 710, 800,1120 rpm simultaneously at constant welding speed 28 mm/min. The experimental setup was shown in the Fig 3 . Using each tool, three joints have been fabricated at three different rotational speeds and in total 6 joints (3X2) have been fabricated. The weldments are shown in the Fig 4.

Fig 3. Friction stir welding Experimental Setup

Fig 4.Weldments of AA6061 and AA6082

To investigate the tensile properties of the weldments, as per ASTM E8M-04 standard the tensile specimens were prepared on CNC wire cut EDM .The prepared samples are shown in Fig 5. The finished specimens were tested to find the ultimate tensile strength (UTS) and %elongation using 40 ton Universal Testing Machine.

Fig 5. Prepared Tensile Specimens

Metallographic specimens were cut mechanically from the welds, embedded in resin and mechanically ground and polished using abrasive disks and cloths. The chemical etchant was the Keller's reagent(1 ml hydrofluoric acid, 1.5 ml hydrochloric acid, 2.5 ml nitric acid and 95 ml water) to reveal the microstructure of the weld region. The microstructures were observed on metallurgical microscope as shown in the Fig 6. Micro hardness of the welds was measured with the test load of 200g. The indentations were made at midsection of the thickness of the plates across the joint. The micro hardness values were measured on Vickers micro hardness tester as shown in the Fig 7

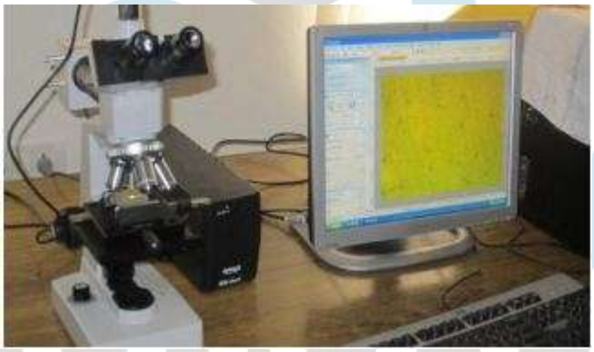


Fig 6 Metallurgical microscope

Fig 7 Micohardness tester

IV. RESULTS AND DISCUSSIONS

Tensile test were performed to determine the tensile properties (yield strength, tensile strength and percentage of elongation) of the aluminum alloy dissimilar combination of AA6061 and AA6082. For the tensile testing of the weldments, two samples from each weldment are made and tested. For results which ever sample has produced better strength is taken in to account. The tensile values of the weldments are shown in the Table III.

Table III Tensile Values of the Weldments

Type of pin profile	Tool Rotational Speed(RPM)	Yield Strength (kN)	Ultimate Strength (kN)	% Elongation
Straight Cylindrical	710	16.080	154.294	6.960
	800	17.098	196.612	8.451
	1120	16.764	178.625	5.845
Cylindrical tapered	710	10.440	142.964	4.860
	800	12.162	187.217	8.928
	1120	11.915	165.012	5.098

The micro structural behavior of aluminum alloys joined by FSW was studied by employing light optical microscope (LOM). Images of weld zones cross section are outlined in Fig 8. In the weld nuggets of all the joints, grains haven been refined as a result of dynamic Recrystallization. Heterogeneous mixing of recrystallized fine grains of 6061 and pancake grains of 6082 had been clearly seen in weld nugget zones. Superior tensile properties for straight cylindrical tool pin profile were observed, this is due to the formation of fine equiaxed grains and uniformly distributed very fine strengthening precipitates in the weld region.

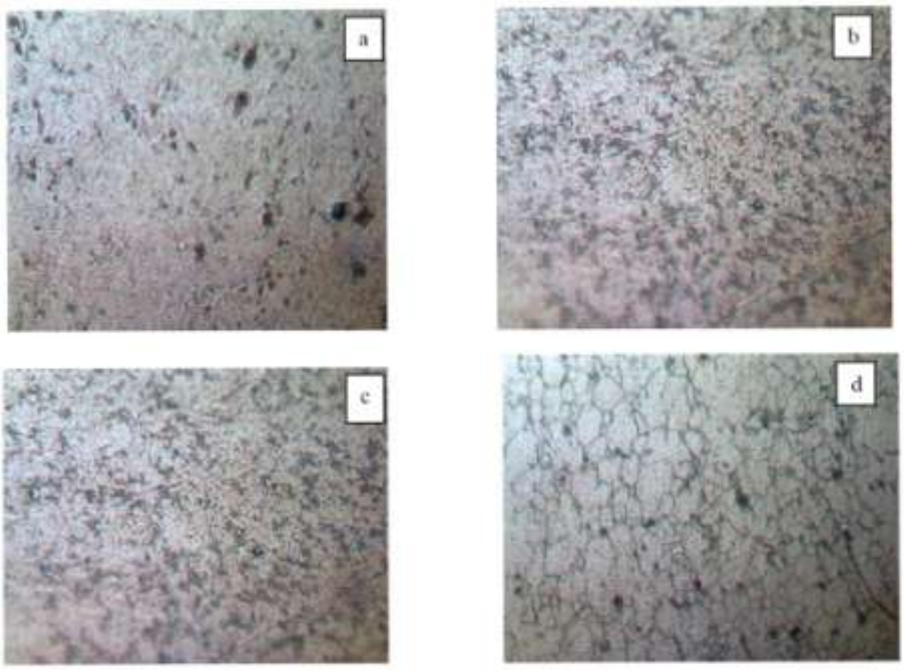


Fig 8. LOM Images of Weld Zones Cross Sections

The micro-hardness indentations of the weldments are shown in Fig 9. Micro hardness tests were performs to determine hardness number values of the aluminum dissimilar alloy combination AA6061 with AA6082 with various tool pin profiles and rotational speeds. The hardness values are shown in the Table IV. that the HARDNESS increases with increase in rotational speed from 710rpm to 1120 rpm, becomes maximum at 1120 rpm and later decreases as the speed increases i.e. from 1120 to 1600rpm. Out of the two profiles selected the cylindrical tool pin has more hardness. The Hardness obtained by cylindrical pin is around 80% of the parent material

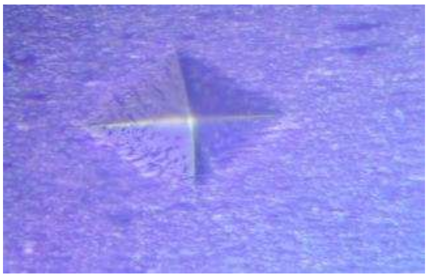


Fig 9. Micro Hardness Indentation of AA6061 And AA6082

Table IV Hardness Values of the Weldments

Type of tool pin profile	Tool Rotational speed (RPM)	Distance from the Weld Centre		
		Advanced Side 9mm	Weld center 0mm	Retreating Side 9mm
Straight Cylindrical	710	59.5	54.6	56.4
	800	76.3	62.4	63.2
	1120	61.5	58.4	60.5
Cylindrical tapered	710	68.4	64.5	66.3
	800	72.5	66.5	69.9
	1120	65.3	63.8	62.4

V. CONCLUSION

The Butt joining of AA 6061 and AA6082 aluminum alloys was successfully carried out using FSW technique. The samples were characterised by mechanical properties like Yield strength, Ultimate tensile strength, Hardness, Percentage of elongation. The following conclusions were made from the present investigation.

- The optimum operating conditions of FSW have been obtained for two plates of aluminum alloys AA6061 and AA6082-T6 welded in butt joint. The Optimal FSW process parameter combinations are rotation speed at 710, 800, 1120rpm, axial force 17 kN and welding speed of 28mm/min.
- The maximum Yield Strength, Ultimate Tensile Strength and Percentage of Elongation 16.080(kN), 154.294(kN) and 6.960% respectively were observed for straight Cylindrical tool pin profile at 1120 rpm.
- The maximum hardness of 76.3 at the weld center was observed for straight Cylindrical tool pin profile.
- The reasons for cylindrical tool pin profile are
    a. More Pulsating action (80 pulse per second)
    b. Flat faces
    c. Reasonable relationship between static to dynamic volume

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